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# The need for greater standardisation in utility power quality measurements

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# The need for greater standardisation in utility power quality measurements

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**Abstract**

The methodology and reasoning behind power quality monitoring by electricity utilities has undergone large scale changes in the past several years. In the past, power quality monitoring has been carried out in a reactive manner; that is, as a result of a specific problem and was usually only conducted in a localised area. Power quality monitoring instrumentation developed to suit fault finding applications and in many cases design was based upon customer requirements rather than a standard specification.

While fault finding is still an essential facet of power quality monitoring, the fact that regulatory authorities are now taking an interest in power quality has meant many electricity utilities are now taking, or indeed are forced to take a more proactive approach to power quality monitoring. This type of monitoring requires different characteristics in a power quality instrument. It is necessary to have standardised instrumentation which can be left in the field over long periods of time. For many years there has been no specific international or Australian standard which outlines the way in which power quality disturbances should be monitored or how power quality surveys should be conducted. IEC standard 61000-4-30 goes some way towards solving this problem detailing how various power quality parameters should be measured and recommending minimum survey periods.

The paper examines some of the issues in routine power quality monitoring. Special emphasis is placed on issues pertaining to measurement standards and measurement techniques. The paper incorporates the experience gained and problems encountered by the Integral Energy Power Quality and Reliability Centre in carrying out power quality surveys.

## 1. Introduction

In [1] power quality is defined as any power problem manifested in voltage, current or frequency deviations that result in failure or maloperation of customer equipment. Examples of power quality disturbances include unacceptable voltage level, voltage supply unbalance, harmonics and voltage sags to name a few. Power quality monitoring is the process of determining the levels of these different power quality disturbances on electricity networks.

Many people mistake power quality for reliability, however, the distinction between the two is not difficult. Reliability problems, which are essentially a loss of supply, will always show an immediate effect on a customer such as the tripping out of a whole installation, whereas in general, power quality problems will not manifest themselves immediately but will cause long-term problems and economic losses such as additional heating in motors leading to loss of service life due to high harmonic levels. However in saying that it should be noted that voltage sags may cause equipment to go offline and high harmonic levels may cause nuisance tripping in some relays.

In the past power quality monitoring has been undertaken by utilities in a reactive manner; that is in response to problems or customer complaints. In such cases power quality monitoring instruments were installed in localised areas for short periods of time to attempt to discern the cause of the problem. There was no need for high accuracy and little or no interest in power quality levels over wider areas of the network or over longer periods of time.

Recently there has been a rise in the interest of regulators and customer awareness of the economic effects of poor power quality. Together with the new environment of higher competition between electricity suppliers, including undertakings by electricity suppliers to provide specified power quality levels to contestable customers, this has lead to many utilities beginning to take a much more proactive attitude toward the measurement of power quality levels on their networks. Combined with the continual connection of modern power electronics equipment which produce and/or are susceptible to power quality disturbances, routine power quality monitoring is becoming increasingly important for utilities in order to plan for and maintain acceptable power quality levels on their networks. Indeed, not maintaining acceptable levels of power quality may now have serious financial and legal implications.

The only effective method of standardising power quality measurement techniques and limits is through Australian standards that are complete and comprehensive, sufficiently strict to ensure accuracy and unambiguous. Without such standards is very difficult for a utility not only to undertake a power quality survey but even to make assurances regarding power quality levels.

This paper will focus on standardisation of measurement techniques and will provide a critique of the current measurement standards. Examples will be used to demonstrate some of the errors and problems which may occur due to either a lack of standardisation or standards being too loosely defined to ensure strict accuracies. Special emphasis is drawn to gaps and ambiguity in the standards, areas where standards are difficult to apply or areas requiring more work.

In order to examine measurement standards, it is first necessary to gain an understanding of exactly why standardisation is so important and how power quality monitors operate and these issues are discussed.

In practice there are other problems that arise in performing power quality monitoring, such as inaccuracies of transducers, which must be recognised and compensated for if standardised measurement techniques are to be achieved. The issue of transducer accuracy is very important for standardised measurement due to the fact that in general as the voltage level rises and, in general, limits for power quality levels become smaller transducer accuracy falls.

## 2. Power Quality Monitoring Instrumentation

### 2.1 Types of Power Quality Instruments

There is a wide variety of instrumentation available that can perform power quality monitoring. These range from expensive and very accurate dedicated power quality monitors though to smart tariff meters whose primary function is to supply revenue or metering data (fundamental voltage and current) but can also have some power quality functionality such as voltage sag and swell detection and monitoring of a limited number of harmonics. These smart tariff meters are generally significantly cheaper than dedicated power quality meters and as they are generally installed in customer premises for metering purposes anyway it is often convenient to also use them to monitor power quality. However, these instruments generally do not comply with any power quality monitoring standards and there are uncertainties over their accuracy for power quality parameters. This lack of standardised measurement techniques and the difficulty in obtaining detailed instrument specifications from instrument manufacturers has meant that it is often difficult to determine the accuracy of power quality instruments.

### 2.2 Power Quality Instrumentation Operation

Power quality monitors must to be able to identify and record the characteristics of many types of power quality disturbances. There are two categories of power quality disturbances. The first category, known as continuous disturbances, is present in every cycle of the waveform and needs to be monitored continuously. The main examples of continuous disturbances are voltage and current variation, voltage unbalance, voltage and current harmonics and flicker. The second category is discrete disturbances or events. These events occur on a purely random timescale and can not be continuous monitored. Discrete events include sags, swells and transients. The monitoring of events is triggered by some monitored value crossing an event trigger threshold. When this occurs the instrument may record event details including duration, classification and waveforms.

Thus a power quality monitor must be able to monitor various parameters changing on a timescale of microseconds (transients) to hours (steady state voltage variations). Fast transients require high sample rate analogue-to-digital converters (e.g. 1-4 MHz) giving a large data throughput.

Any significant power quality survey will produce very large amounts of data. The process of sampling waveforms and aggregating data to a usable form is quite a complex operation. Figure 2 shows a simplified view of the methods used by power quality monitors to reduce data to a useable form. As shown waveforms are sampled at a high frequency (up to 256 samples/cycle), this data is then aggregated to what is generally described as a short time period. These short time periods are then further aggregated to give one value over the measurement period.

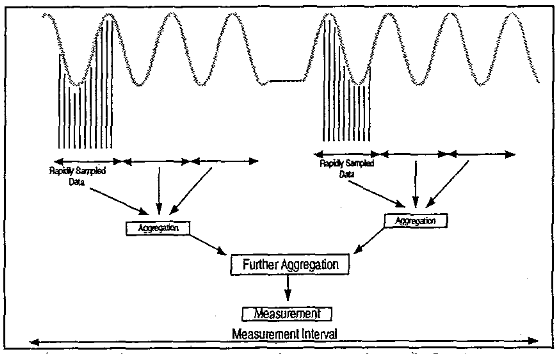

**Figure 2: Simplified view of aggregation methods**

When conducting a power quality survey one of the most important parameters to decide upon is the reporting interval. The reporting interval dictates how often an instrument will store a measurement value for later analysis. Possibly even more important than the recording interval is how the instrument manipulates the data in order to aggregate it down to the recording interval. Take the example of voltage magnitude. With a recording interval of 10 minutes the simplest method of producing one value for voltage magnitude every 10 minutes is to take one spot measurement at an arbitrary time during the 10 minute interval. Obviously this method is very inaccurate as it is impossible to determine whether the measurement was taken during a peak or a trough in the voltage magnitude. At the other end of the scale there are instruments which are sampling very quickly and calculating rms values every ½ cycle. These ½ cycle values are then further averaged to give 10 minute values. Obviously this type of analysis gives much more accurate measurements but it also requirements much more processing power and storage capability onboard the instrument. Thus it is essential to find a happy medium between accuracy, instrument memory and instrument processing power.

## 3. Why is Power Quality Measurement Standardisation Necessary?

Power quality monitoring essentially consists of two stages. The first stage is the monitoring itself. This is carried out by equipment capable of measuring various power quality disturbances. Electricity utilities will often have many sources of power quality data from many different types of monitoring equipment. These range from expensive and very accurate power quality monitors through to cheaper smart revenue meters. Each instrument used by a utility will have its own unique accuracy and measurement protocols.

The second stage of power quality monitoring consists of the assessment procedure. The assessment procedure consists of comparing data obtained by the monitoring equipment with limits or planning levels to determine the 'health' of the network.

The need for greater standardisation in utility power quality measurements is obvious. With so many sources of data it is essential that strict and unambiguous standards detailing measurement techniques and accuracies are available so that data measured by a range of equipment is comparable. In essence measurement methods must be standardised so that measurements are consistent and like can be compared to like.

In the current regulated electricity environment utilities have an obligation to provide levels of power quality that comply with regulatory requirements and customer connection agreements. There are financial and legal implications for utilities which fail to meet these obligations. Without standardised measurement and assessment processes it is impossible to determine the exact power quality levels on the network. In the cases where limits for disturbances are low such as unbalance and higher order harmonics, the measurement protocol and accuracy of the instrument used for the power quality monitoring can mean the difference between complying with limits or agreements and exceeding them. In cases where it is uncertain whether or not power quality levels are in excess of agreed limits only standardised instrumentation can be used to solve disputes between parties. Studies [2, 3] have shown large discrepancies between instrument accuracies for harmonics and flicker.

### 3.1 Example of the need for standardised measurement – Unbalance Measurement

A good example to demonstrate the need for standardised measurement techniques is the measurement of supply voltage unbalance. In [1], unbalance or more specifically, voltage unbalance, is defined as a condition in which the three phase voltages differ in amplitude or are displaced from their normal 120 degree phase relationship or both. There are several factors which can have an effect on the accuracy of unbalance measurements presenting a very complicated problem if standard measurement techniques are not used. The first factor is the method which the instrument uses to calculate unbalance. There are two methods of calculating unbalance. The first method requires instrumentation that can measure and separate the negative sequence voltage from the positive sequence voltage. In this method unbalance is simply calculated by dividing the negative sequence voltage by the positive sequence voltage and expressing as a percentage. The second method involves using three measured line-to-line voltages to calculate the unbalance using formulas.

The two methods should give approximately the same result as long as line-to-line voltages are used. However, if line-to-line voltages are not available, and line-to -neutral voltages are substituted for line-to-line voltages, the additional zero sequence in the line-to-neutral voltage will produce inaccuracies.

More importantly, the calculation of unbalance is greatly affected by the sampling period or the regularity with which unbalance measurements are calculated. There are a multitude of ways in which an instrument may measure unbalance, however studies [4] have shown that if unbalance is not calculated using correct methods there may be a ±30% difference between unbalance levels which are calculated correctly and those calculated using other methods such as using one set of voltage measurements over a 10 minute interval. Take the example shown in Figure 1 which shows three voltages, Va, Vb and Vc. It can be seen that Va varies in exact opposite to Vc. Over 1 cycle the average voltage of Va will equal the average voltage of Vc and Vb. Thus if unbalance is calculated over 1 cycle it will be zero. However over ½ a cycle there is consistent unbalance. Thus it can be seen how incorrect or non-standardised averaging procedure may disregard high frequency unbalance effects and give a false reading.

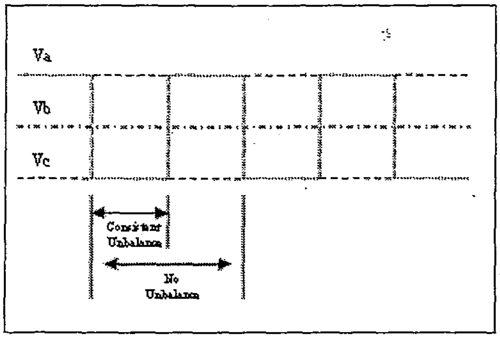


**Figure 1: Unbalance Example**

## 4. Power Quality Monitoring Standards

### 4.1 IEC 61000-4-30

While standards concerning limits of various power quality disturbances have been in use for some time and standards such as EN50160 [5] and IEEE 1159 [6] provide some details on performing and evaluating power quality surveys. Until the release of IEC 61000-4-30 [7] in 2003 no standard has specifically and extensively described methods of conducting power quality surveys and measuring power quality disturbances. In the past, most measurement functions including accuracy, sampling frequency and data aggregation methods have been at the discretion of the instrument manufacturer and were often driven by specific customer requirements rather than with a view to following standardised measurement protocols. Consequently, it has been difficult to compare the results of a survey made with one type of instrument with those of another type of instrument.

The scope of the IEC 61000-4-30 is to define the methods for measurement and interpretation of results for power quality parameters. Quoting form the standard; "Measurement methods are described for each relevant parameter in terms that will make it possible to obtain reliable, repeatable and comparable results regardless of the compliant instrument being used and regardless of environmental conditions" [7]. IEC 61000-4-30 is a performance specification, not a design specification, meaning that it does not specify exact instrument details such as sampling frequency, however, it describes many of the most important factors which need to be considered when undertaking power quality surveys. These factors include instrumentation accuracy, measurement techniques and aggregation periods. The standard also provides informative guidelines on minimum assessment periods and recommended reporting intervals. Power quality disturbances covered directly by the standard are voltage and current variation, voltage unbalance, frequency, voltage dips and swells. The standard calls IEC 61000-4-7 [8] for harmonics and interharmonics measurement protocols and accuracy and IEC 61000-4-15 [9] for flicker measurement protocols and accuracy. The only major power quality disturbance not covered by the standard is transients and there is currently no standardised method for measuring and evaluating transients.

The focus of IEC 61000-4-30 is to describe the way in which instruments should operate to produce standardised and repeatable measurement results. To achieve these ends, the standard outlines two classes of instrument. Class A instruments are very precise and comply with strict accuracy limits and methods of data sampling and aggregation. Class B instruments are of less interest here as their specifications are stated by the manufacturer. This classification of instruments leads to one of the greatest benefits of the standard, that is, the standard ensures that any two instruments complying with class A and measuring the same signal should record the same result within the strict tolerances of the standard.

### 4.2 Problems and Shortcomings of IEC 61000-4-30

While IEC 61000-4-30 is a huge improvement in ensuring standardised measurement techniques there are still some major flaws which need to be addressed.

One of the more difficult aspects of the standard to implement is the concept of 'flagging' of data. Flagging of data is used to avoid counting an event more than once in different parameters (for example counting a voltage sag as a sag as well as a voltage variation). Continuous data recorded during a sag, swell or interruption is flagged in order to indicate that the presence of an event that may produce an unreliable result. Many standards call for flagged data to be removed before comparison with limits. At present there are very few instruments which have data flagging capabilities and it is often necessary to manually cross reference event tables with continuous data to remove events, this is a very tedious and time consuming process. One major problem with removing flagged data occurs in the case of flicker. The long term flicker index or $P_{lt}$ is calculated using 12 consecutive short term flicker ($P_{st}$) indices using a sliding window. This means that one flagged $P_{st}$ value will affect 12 $P_{lt}$ values which would all need to be removed before comparisons could be made with limits. If several events occur over a monitoring period, the loss of only a few $P_{st}$ values could result in the loss of a large number of $P_{lt}$ values severely affecting the accuracy of the survey. Methods which should be used in this scenario are not detailed at all in the flicker assessment standard AS/NZS 61000.3.7 [10] and this is one major fault of the flagging concept.

Another detail not handled well by IEC 61000-4-30 is the aggregation of data to non-standard time periods. IEC 61000-4-30 outlines a series of standard measurement time intervals, for a 50Hz system these are 3 seconds, 10 minutes and 2 hours. The methods that should be used to aggregate data to these time periods are explicitly detailed. However many instrument manufacturers and many instrument users like to incorporate measurement intervals other than the three standard intervals. IEC 61000-4-30 gives no indication of the aggregation methods that should be used to obtain these non-standard measurement intervals.

### 4.3 Problems with IEC 60000-4-7

IEC 61000-4-7 which is the standard called by IEC 6100-4-30 detailing harmonic and interharmonic measurement techniques, is also very ambiguous and open to various methods of interpretation. This standard allows for a 5% accuracy in the entire input circuit. Given that the accuracy required by IEC 61000-4-30 for voltage measurement by class A instrumentation is 0.1%, an accuracy of 5% for harmonics measurements appears to be large and gives scope for two instruments that are compliant with the standard to record measurements that are considerably different.

### 4.4 Problems with IEC 61000-4-15

IEC 6100-4-15 which is called by IEC 61000-4-30 for methods that should be used for flicker monitoring has been found to be quite difficult to understand and apply to instrumentation. There is a large degree of design freedom allowed in this standard in fact the accuracy required by the standard is 5% which again is large when compared to the voltage accuracy required by IEC 61000-4-30 for class A instrumentation, which is 0.1%. Flicker measurement studies [3] have shown that the requirements IEC61000.4.15 are interpreted differently by instrument manufacturers and the standard lacks sufficient explicitly to ensure that all flickermeters will respond the same way to all input signals. In fact [3] shows that the errors between instruments which fully comply with IEC 61000-4-15 can be very large. Obviously the standard needs to be amended or updated to greatly reduce these errors.

In addition the standard has many ambiguities which make it difficult to design and construct a flickermeter. IEC 61000-4-15 contains specification for analogue designs while most modern instrument are digital. IEC 61000-4-15 does not have any specification for attributes required by digital instrumentation such as sampling rate and resolution. Design of the input filters has been found to be difficult and sampling rate which is not specified by IEC 61000-4-15 has been found to be a critical component of the filter design. The testing regime required by IEC 61000-4-15 is also very time consuming and obtaining equipment to perform these tests is difficult.

## 5. Practical Power Quality Monitoring Issues

### 5.1 Connection Issues

In the field it is often difficult to perform a power quality survey exactly as the standards describe. These practical issues may have a large bearing on the quality of data retrieved from a power quality survey. Utility network configurations such as the availability of transducers often mean that some signals may be missing or unable to be monitored. In addition some power quality instruments require special connection methods (for example line-to-neutral connection) that may not always be available especially in medium voltage systems.

### 5.2 Transducer Issues

Arguably the most difficult practical concern of power quality monitoring to overcome is the issue of transducer accuracy and frequency response, especially at higher voltage levels. No instrument will be able to connect directly to medium or high voltage lines, thus, voltage and current transducers are required to reduce signals down to a level that can be accommodated by the instrumentation. Very few (if any) transducers will have the accuracy of any IEC 61000-4-30 class A compliant instrument. Thus the use of transducers will introduce additional errors into power quality measurement and these must be taken into account when data is analysed.

Possibly the most difficult power quality disturbance to monitor at higher voltage levels is voltage harmonics and this is due to transducer frequency response. Accurate measurement of harmonics is very much dependant on the frequency response of the transducer being used.

At low and medium voltage levels inductive voltage transformers are generally used. Studies completed on the frequency response of voltage transducers [11, 12] have shown that in general inductive voltage transducer frequency response should be acceptable for harmonic measurement up to at least the 20$^{th}$ harmonic or 1kHz and this is confirmed by AS/NZS 61000.4.7 [13]. However, even if a voltage transducer possesses adequate frequency response to the 20$^{th}$ harmonic, and this is not guaranteed, many standards call for assessment of harmonics to the 50$^{th}$ order and this is impossible with most if not all voltage transducers. At higher voltage levels capacitive voltage transducers are often used. Theoretically, the frequency response of these transducers should be acceptable over any practical measurement range, however, these transducers are often used with inductive transducers to produce a tuned circuit suitable for measurement only at the fundamental frequency, and thus harmonic measurements are impossible using these transducers.

Transducer inaccuracy at higher voltage levels also makes measurement of unbalance at high voltage almost impossible. Although unbalance measurement only requires the fundamental voltage and hence frequency response is not an issue, typical accuracy of high voltage transducers is of the order of 1%. Considering that unbalance levels at high voltage are usually much less than 1% the situation is that the inaccuracy of the transducer is larger than the expected measurement result. Obviously such high inaccuracy deems measurement impossible.

## 6. Conclusions and Recommendations

Changes in the electricity supply industry in Australia over the past few years have seen a growth in the awareness of the economic implications of power quality problems, corresponding to a shift in the rationale behind power quality monitoring by utilities. Utilities have now moved away from a reactive power quality monitoring strategy to more proactive strategies due to increased customer awareness and increased regulation. The paper has detailed this shift in mindset, outlined the problems with some of the standards and detailed some of the practical obstacles remaining for utilities attempting to undertake standardised power quality monitoring surveys.

Utilities will obtain power quality data from a range of instruments and there are inconsistencies between these instruments. Complete standards are necessary to ensure that the data measured by one type of instrument is comparable to that measured by a different type of instrument. It has been shown that complete standards are essential for effective power quality monitoring and the example given of unbalance measurement demonstrates the problems that may occur if standardised measurement techniques are not used.

IEC 61000-4-30 released in 2003 describes a detailed performance specification for power quality instrumentation as well as the methods that should be used in conducting and evaluating power quality surveys.. However, there are still significant ambiguities and difficulties in application with this standard as well as some of the standards that it calls. Therefore it is crucial that these standards outlining instrumentation operation be further modified to improve accuracy and repeatability of measurements, reduce ambiguity and to include all major power quality disturbances.

Some practical problems in undertaking power quality surveys have been discussed. The difficulties of performing power quality monitoring at higher voltage levels have been indicated. There is much work still to be done regarding methods of using high voltage transducers for effective power quality measurement.

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